Clean Power Generation From Heavy Residues
The LURGI SGP-IGCC Concept

Christopher Higman and Gerhard Grünfelder
presented at the Conference "Power Generation and the Environment"
Institution of Mechanical Engineers
London, November 1990

Clean Power Generation From Heavy Residues

The LURGI SGP-IGCC Concept

Christopher Higman

Synopsis

The current paper shows how gasification of residual oils can be integrated into a power generation scheme using the Integrated Gas Combined Cycle (IGCC) and realize considerable economic and environmental advantages compared with conventional combustion with flue gas desulphurization.

1 Introduction

Current economic and particularly environmental pressures are providing an incentive for both the petroleum refining and the power industries to re-examine various options for the continued technical development of their operations. In the power industry it will be increasingly difficult to gain political acceptance for nuclear power - but at the same time levels of allowable sulphur and NOx emissions are being reduced. Lately also CO2 has become the object of criticism. The restriction on sulphur emissions will also have repercussions on the refining industry, which will have to lower the sulphur content of the fuel oil pool. A number of the bottom-of-the-barrel schemes for processing the heavier fractions of the crude oil produce a heavy residue or asphalt for which an outlet must be found. Table 1 shows typical specifications for such residues.

In the past such residues have been gasified for the production of synthesis gas for methanol, ammonia or hydrogen production. However, both the ammonia and the methanol markets have become saturated and a refinery material balance can only absorb a limited amount of hydrogen. It would therefore seem logical to review the possibilities of power production as a sink for the residues with their high sulphur and metal contents while simultaneously reducing the environmental burden of power generation.

Feedstock Type		**Visbreaker Residue**	**Propane Asphalt**
Elementary Analysis			
C	[wt%]	85.42	84.37
H	[wt%]	9.93	9.67
S	[wt%]	4.00	5.01
N	[wt%]	0.30	0.52
O	[wt%]	0.20	0.35
Ash	[wt%]	0.15	0.08
		100.00	100.00
Vanadium	[ppmw]	270	300
Nickel	[ppmw]	120	75
Sodium	[ppmw]	30	30
Viscosity (100 °C)	[cSt]	10 000	2 000
Density (15 °C)	[g/cm³]	1.10	1.07

Table 1: Typical SGP Feedstocks

2 The LURGI SGP-IGCC Concept

2.1 Historical Background

The basic concepts of the IGCC power cycle have been around for a long time. Partial oxidation using the already established SHELL Gasification Process (SGP) in combination with the combined-cycle was being discussed as a non-polluting method for power generation from high-sulphur residues in the early 1970's (1). Since then the process has continued to be applied for a wide field of uses in the chemical industry, while the emphasis of development work for power generation applications has gone into improvements in coal gasification and gas turbine technology (2, 3, 4 and 5).

Economic conditions have discouraged the introduction of IGCC technology on a large scale, whether for coal or heavy residue feeds. Nonetheless operational experience has been gained in two coal-based IGCC plants in the United States (Cool Water 100 MW and Plaquemine 160 MW). A 250 MW IGCC power plant using the SHELL Coal Gasification Process is under construction at Buggenum in the Netherlands. Some of the advances made over this time are equally applicable to oil-based IGCC plants, so the purpose of this paper is to provide an update on this option.

2.2 Overall Cycle

The block diagram in Figure 1 provides an overview of the overall process.

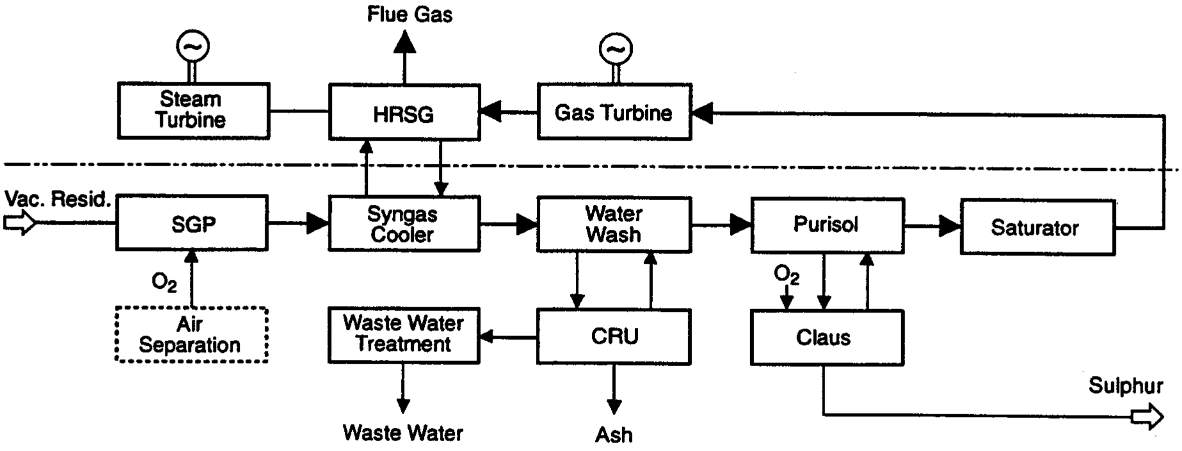

Figure 1:SGP-based Integrated Gasification Combined cycle

The feedstock is gasified in the SGP reactor with air or oxygen to produce raw synthesis gas at a temperature of about 1300 °C and a pressure of typically about 30 - 35 bar. This gas is a mixture of hydrogen and carbon monoxide which however also contains CO_2, H_2S and COS together with some free carbon and the ash from the feedstock. If air is used as oxidant it is further diluted with ca. 55 - 60 % nitrogen.

The hot gas is cooled in the synthesis gas cooler by generating high pressure steam. Particulates are removed from the gas using a water wash prior to desulphurization. The desulphurized gas is resaturated with water vapour, which improves efficiency and contributes to NOx reduction prior to combustion in the gas turbine

The hot saturated gas is combusted and expanded in the gas turbine, which drives a power generator. The hot exhaust gas from the gas turbine is used to generate high pressure steam to drive the steam turbine.

The wash water from the particulate removal is treated in the carbon recovery unit. Carbon and ash are extracted separately from the water using naphtha as an intermediate. The carbon is recycled to the SGP reactor. The bulk of the water is recycled to the water wash.

The desulphurization solvent regeneration system incorporates a Claus unit, which converts the hydrogen sulphide into elemental sulphur.

3 Process Descriptions

3.1 SHELL Gasification Process

3.1.1 Choice of Oxidant

There is a fundamental choice between gasifying the residue with air and gasifying with oxygen. On paper there is not much to choose between the two. The decreased size of the gas production and treating equipment and of the steam cycle for an oxygen-blown system almost exactly compensates the additional investment cost of the air separation unit. Similarly, the operating cost savings achieved by not compressing all the nitrogen in the air to the gasification pressure more or less balances the energy requirement of the oxygen plant. While the chemical requirements of most SGP applications have dictated the use of oxygen, about 10 % of SGP units use air. LURGI therefore offers both alternatives, a final decision being related to other project specific factors.

Figure 2 provides a more detailed look at the gasification unit.

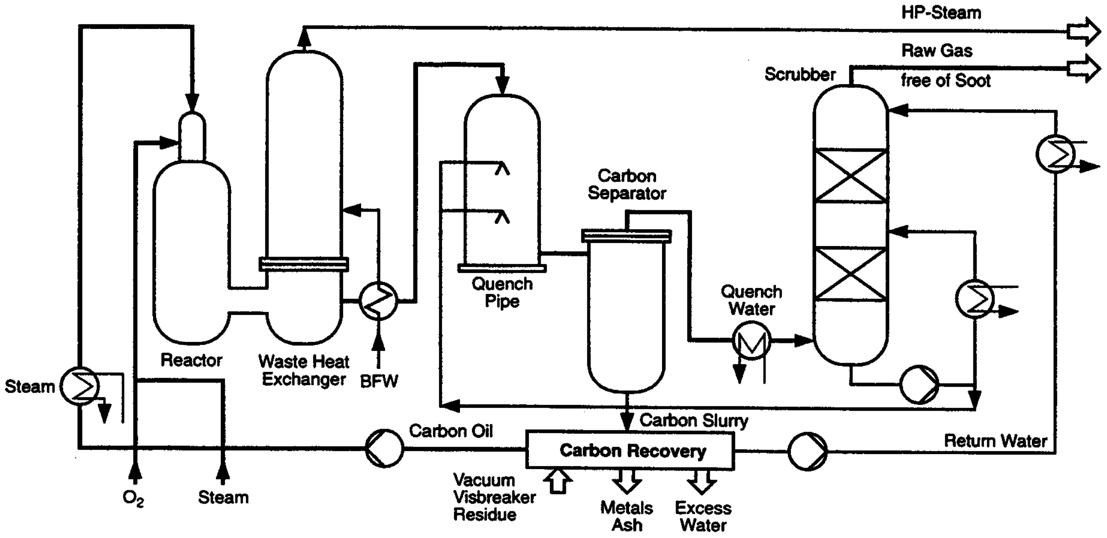

Figure 2: SHELL Gasification Process

3.1.2 Gasification

The non-catalytic partial oxidation of hydrocarbons by the SHELL Gasification Process takes place in a refractory-lined reactor, which is fitted with a specially designed burner. The oxidant is preheated and mixed with steam prior to being fed to the burner. The burner and reactor geometry are so designed that this mixture of oxidant and steam is intimately mixed with the preheated feedstock.

3.1.3 Waste Heat Recovery

The product of the partial oxidation reaction is a raw synthesis gas at a temperature of about 1300 °C, which contains particles of residual carbon and ash. The recovery of the sensible heat in this gas is an integral feature of the SGP process.

Primary heat recovery takes place in a waste heat exchanger generating high pressure (100 bar) saturated steam in which the reactor effluent is cooled to about 340 °C. The waste heat exchanger is of a special design developed specifically for these operating conditions and used in about 135 installations world-wide. Part of the steam thus generated is used for feedstock and oxidant preheating; the remainder is fed to the combined cycle section for superheating and use in the steam turbine.

Secondary heat recovery takes place in a boiler feed water economizer immediately downstream of the waste heat exchanger.

3.1.4 Carbon Removal

In the partial oxidation of hydrocarbons the product gas contains a certain amount of free carbon. The plant is designed for a free carbon content in the gas (carbon make) equivalent to about 1 wt. % of the reactor feedstock. The carbon particles are removed from the gas together with the ash in a two-stage water wash

This consists of a quench pipe and carbon separator followed by a packed tower, the carbon scrubber. In the quench pipe ca. 95 % of the carbon is removed by direct water spray. In the scrubber the gas is washed in countercurrent flow in two packed beds. A circulation system is employed over the lower bed using a circulating pump. The upper bed is washed with return water from the carbon recovery section.

The carbon formed in the partial oxidation reactor is removed from the system with the process condensate as a carbon slurry. This slurry has a carbon content of ca. 1 % carbon. It is then processed in the carbon recovery unit described below. After carbon removal this water is then recycled as return water to the top of the scrubber.

After leaving the scrubber with a temperature of about 40 °C the gas has a residual carbon content of about 1 mg/m3 and is suitable for feeding to the desulphurization unit.

3.1.5 Carbon Recovery Unit

Figure 3 illustrates the principles of the carbon recovery unit. The carbon and ash-containing water from the SGP is contacted with naphtha in an extractor in which naphtha and carbon agglomerate to form sievable pellets. The naphtha-carbon pellets are separated from the water and the ash in a sieve and then mixed in with the fresh feedstock. The naphtha is distilled off in a two-stage flasher-stripper system and recovered for recycling to the extractor. The carbon is left in the feedstock and recycled back to the SGP reactor as carbon oil.

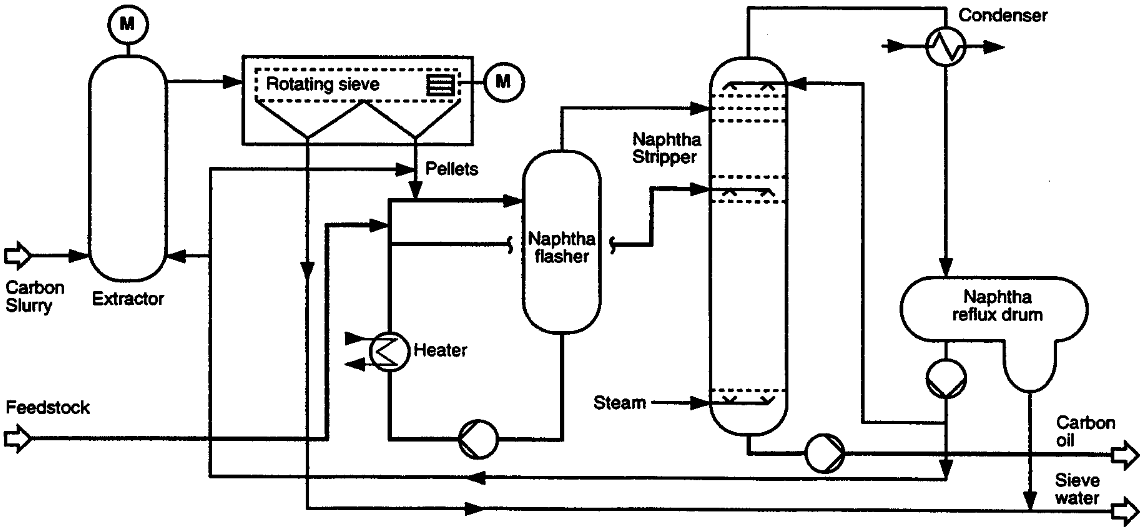

Figure 3: Naphtha-Soot Carbon Recovery Unit

3.1.6 Waste Water Pre-treatment

The rundown water from the sieve contains traces of naphtha and the ash. In the waste water pre-treatment section shown in the Figure 4 the bulk of the water is recovered for reuse as wash water for carbon removal. First the naphtha is stripped out and returned to the naphtha circuit. Then the ash is separated from the water and demoisturized in a filter press. The filter cake thus produced is a saleable by-product containing 25 % - 30 % wt of vanadium. This degree of treatment is sufficient for the recycle water.

However, the overall system generates a net water surplus, which must be further treated before final discharge. The first step is a sour water stripper in which dissolved gases such as H_2S, CO_2 and ammonia are removed. The stripped gases are incinerated in a special burner in the Claus unit and therefore kept entirely within the system. Final water clean-up takes place in a flocculation-sedimentation system for trace metal (ash) removal and a biological waste water treatment unit.

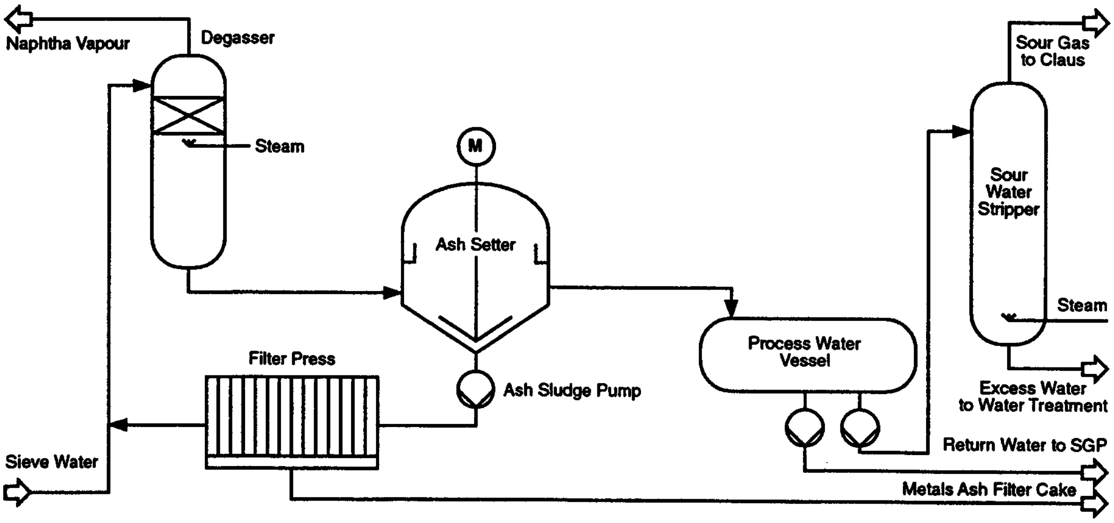

Figure 4: SHELL Gasification Process – Waste Water Pre-treatment

3.2 PURISOL Desulphurization

There is a wide variety of solvents available for desulphurization of the raw gas. When selecting the optimum solvent for an IGCC plant there are a number of important factors to consider.

(a) **Selectivity**. All desulphurization solvents absorb a certain amount of CO_2. In many circumstances this is of no great importance, but to the IGCC coabsorption represents a loss of mass flow to the gas turbine as well as inflating the cost of the Claus and recompression sections. A high selectivity between H_2S and CO_2 is therefore required

(b) **Carbonyl Sulphide**. In general one finds that the solubility of carbonyl sulphide (COS) is substantially lower than that of H_2S and is thus the limiting factor in the desulphurization process. For high sulphur recovery rates it is therefore necessary to look for a solvent with a high COS solubility or introduce an additional catalytic process stage to remove the COS.

The solvent of LURGI's PURISOL desulphurization process, N-methyl-2pyrrolidone (NMP) meets these two basic requirements. Over the last few years the process has been further optimized specifically for the IGCC application (6).

Complementing the Purisol washing system, a Claus unit converts the gaseous sulphur compounds in the Purisol waste gas to elemental sulphur. In LURGI's optimized flow scheme the Claus tail gas is recycled to the Purisol wash thus eliminating completely any sulphur emissions from the Claus unit and simultaneously removing the need for separate tail gas treatment.

The basic outline of the Purisol desulphurization unit is shown in Figure 5. The raw gas from the SGP unit is washed with NMP in the H2S absorber. The NMP absorbs the H_2S from the raw gas. By hydrolysing the COS to H_2S the NMP also indirectly absorbs the COS. The gas leaves the absorber with a residual H_2S plus COS content of typically 20 - 40 ppmv. Lower values can be achieved with only a minor increase in capital cost.

The loaded NMP undergoes an intermediate flash at a pressure of about 2 bar releasing most of the coabsorbed CO_2, CO and H_2. This flash gas is recompressed to the absorber. The NMP is subjected to a further hot flash and hot regeneration before being recycled to the absorber.

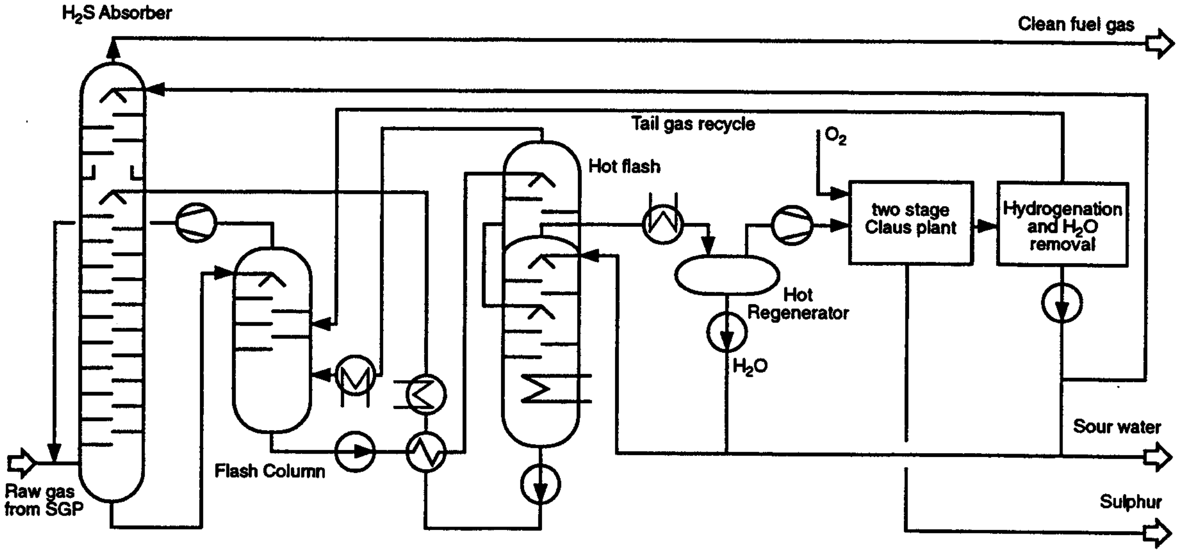

Figure 5: Purisol Desulphurization Unit

The off-gas from the regenerator is treated in a Claus unit in which the H_2S and COS are converted to sulphur using either air or oxygen according to the oxidant selection in the gasification unit.

Under the conditions of the Claus furnace considerable quantities of H_2 and CO are formed. This hydrogen is sufficient to hydrogenate the remaining sulphur compounds in the tail gas to H_2S in a catalytic hydrogenation reactor. The tail gas is recycled to the flash column, from which the H_2S is returned to the Claus unit and non-sulphur components are recompressed to the absorber.

3.3 The Combined Cycle

Figure 6 shows the combined cycle part of the plant. The desulphurized gas is preheated and water saturated using lower grade heat from the gasification. It is then used as fuel in the gas

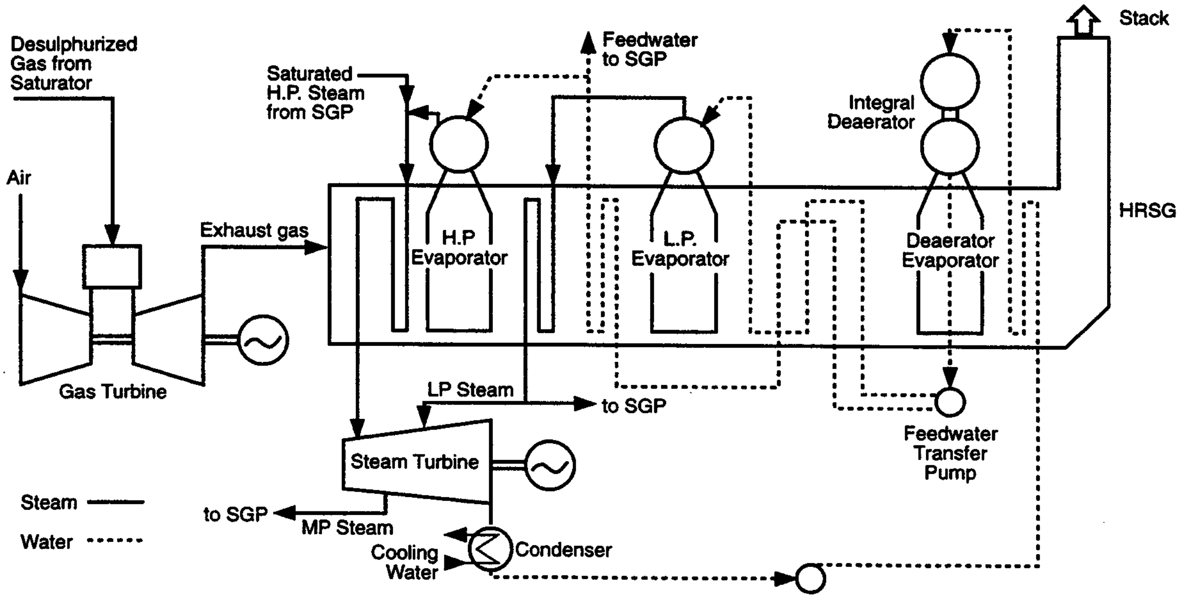

Figure 6: Combined Cycle Power Plant

turbine, which drives a generator. The exhaust gas from the turbine has a temperature of ca. 550 °C. It is used to generate high pressure steam and superheat it together with that from the synthesis gas cooler in the Heat Recovery Steam Generator (HRSG).

Additional coils in the HRSG are used to preheat boiler feedwater and generate low pressure steam. The steam is used to drive a condensing steam turbine, a 40 bar extraction from which is used as process steam in the SGP unit.

4 Economic and Technical Data

4.1 Overall Efficiency

The following figures show what can be achieved with this system. They have been prepared for a 200 MW station based on a typical heavy residue - a vacuum visbroken residue with high sulphur (4,2 %) and high metals (270 ppmw vanadium) content. A full specification of this feed is listed in Table 1.

Tables 2 and 3 lists the principle fuel gas properties and performance data of the unit. These figures are based on the use of a Nuovo Pignone MS 9000/E gas turbine. A 350 MW unit based on the larger MS 9000/F turbine would achieve about 44 % efficiency.

Composition		
CO_2	[mol% dry]	3.29
CO	[mol% dry]	51.22
H_2	[mol% dry]	43.75
CH_4	[mol% dry]	0.10
N_2 + Ar	[mol% dry]	1.64
H_2S	[ppm v]	10
COS	[ppm v]	10
Particulates	[mg/Nm^3]	<1
Flow to saturator	[Nm^3/h dry]	120 428
Flow to saturator	[Nm^3/h wet]	166 463
LHV dry basis	[kJ/Nm^3]	11 224

Table 2: SGP-based IGCC Fuel Gas Properties

4.2 Operating Characteristics

SGP reactors exhibit good turndown capability. Currently available reactor designs cover a range up to ca. 45 t/h feedstock, equivalent to a 200 MW IGCC on a single reactor using oxygen for gasification. The same output using air or a 350 MW unit would require two reactors.

Load-following characteristics of SGP allow it to be operated in a "turbine- lead"-mode achieving a response of 3 % per minute (7). The Purisol desulphurization process also exhibits good load following characteristics (6). Availabilities of 95 % and more for SGP units are regularly achieved (8).

Feedstock	[kg/h]	40 850
Byproducts		
Sulphur	[kg/h]	1710
Vanadium cake	[kg/day]	350
Gas turbine output	[MW]	132.2
Steam turbine output	[MW]	74.2
Less Auxiliaries	[MW]	24.4
Net Output	[MW]	182.0
Nett Efficiency	[%]	41.2

Table 3: SGP-based IGCC performance data

4.3 Environmental Characteristics

Table 4 has been prepared as a means of evaluating the environmental characteristics of the SGP-IGCC power plant concept. The values under the heading "Emission Limits" are drawn from current German legislation, which in the case of flue gas by and large reflects state-of-the-art technology for combustion systems with flue gas treatment for SOx and NOx removal. In the case of water regulations, there is no unified system of standards in Germany - still less in Europe - so that the values are drawn from the most appropriate legislation available.

Pollutant		**SGP-IGCC**	**Emission Limits**	**Regulation**
Flue Gas				
SO_x	[mg SO2/m³]	20 - 40	400	13. BImSchV
Sulphur recovery	[%]	99.6 - 99.8	85	13. BImSchV
NO_x	[mg NO2/m³]	60 - 150	150	Umweltminister Konferenz 5.4.84
Particulates	[mg/m³]	<0.5	50	13. BImSchV
Waste Water				
Vanadium	[mg/l]	<2	3	31. Abwasser VwV
			2	City of Hamburg
Nickel	[mg/l]	<1	3	City of Hamburg
BOD_5	[mg/l]	<20	25	45. AbwasserVwV

Table 4: SGP-based IGCC: Environmental Characteristics

Inspection of the table will show that in all cases the SGP-IGCC meets current standards and that in the case of some pollutants it offers an order-of-magnitude improvement against current technology.

4.3.1 Sulphur

The most conspicuous difference between the legislative requirements and the values obtainable with an SGP-IGCC is in the area of desulphurization. While the expectations for economic desulphurization of flue gas do not go much below 200 mg/m3, the 20 - 40 mg/m3 quoted on the basis of desulphurization of the fuel gas could be reduced still further using proven technology without substantial increase in capital or operating expenditure.

4.3.2 Nitrogen Oxides

The overwhelming proportion of NO_x emitted by an oil-based combined cycle power station is thermal NO_x generated in the combustion chambers of the gas turbine. Primary measures at the burner are sufficient to meet today's standards. Looking to the future, secondary measures such as selective catalytic reduction (SCR) offer the prospect of a further order-of-magnitude reduction in NO_x emissions (9).

4.3.3 Particulates

The low particulate emission level is another conspicuous feature of the SGP-IGCC attributable to the SGP carbon removal system in which practically all particulates are washed out of the gas with water.

4.3.4 Ash and Waste Water

When looking at the environmental aspects of an oil-fired power station, one has to review the effects of the ash present in the fuel, important components of which are toxic heavy metals such as vanadium and nickel.

In the SGP-IGCC power station these metals are washed out of the main gas stream with the carbon and so do not appear in the flue gas, where in conventional systems a proportion is discharged as particulate emissions. The metals are separated out as a solid filter cake within the carbon recovery unit. This filter cake is a valuable raw material and two operators of vacuum residue-fed SGP units are selling this by-product to the metallurgical industry, thus achieving a zero-solid-waste situation. The combination of stripping, flocculation/ sedimentation and biological treatment ensures a satisfactory quality of waste water discharge.

4.3.5 Non-regulated Pollutants

In the development of technology, we have to look to the needs of the future as well as meeting the demands of today's legislation. In two further areas the IGCC offers environmental advantages over current technology. The high efficiency of the SGP-IGCC power plant is not only of economic benefit but contributes to a reduction in carbon dioxide emissions - by 5 % or more. In view of the current debate on the "greenhouse effect" this must be considered as an additional environmental advantage.

The use of a combined cycle also reduces the cooling water requirement substantially and thus also reduces thermal pollution.

4.4 Costs

The surprising aspect of the SGP-IGCC system is that in addition to offering increased efficiency and improved environmental performance, it is also cheaper than conventional technology.

The investment costs for the system described i.e. air separation (if used), gasification, desulphurization and combined cycle together with the fresh water treatment, waste water treatment and cooling water facilities are of the order of magnitude of DM 2100 - 2300 per net KW output, depending on site location and exact specification.

The nature of the plant is such that very little of this can be attributed specifically to pollution control except the waste water treatment which only amounts to some DM 20/KW.

For a conventional oil-fired power plant equipped with flue gas treatment to meet current emission regulations one must expect to invest some DM 2400 - 2600 per installed KW.

Given that fuel and capital charges represent some 30 - 35 % and 40 - 50 % of power production costs respectively, the higher efficiency and lower investment would reduce overall production costs by some 5 - 6 %.

5 Conclusion

The SGP-IGCC Concept presented here is a means of utilizing heavy refinery residues for power generation using proven industrial processes with high efficiency, while simultaneously minimizing the environmental impact without increased cost.

Acknowledgement
The authors wish to acknowledge the help received from Nouvo Pignone and Turbotecnica in preparing the combined cycle section of this paper.

References

[1.] **van den Berg, G.T., van Doorn, P.J.J., Haeberli, W.A., “**Kraftwerke mit schwefelfreiem Abgas“, Verfahrenstechnik 5, 1971 Nr. 10 pp 406-408

[2.] **Kehlhofer, R., et al**, „Kombi-Kraftwerk mit BGL-Kohlevergasung für die Mittellast im Vergleich zu konventionellen Kohlekraftwerken“, VGB-Kraftwerkstechnik 68, 1988, Vol. 12, pp 1264 - 1268

[3.] **Anon**, Modern Power Systems, August 1988 pp 53-59

[4.] **Gusso, R.** “Moderne centrali a ciclo combinato per generazione di energia elettrica”. Quaderni Nuovo Pignone 1989

[5.] **Schmoch, O., Deblon, B.** „Die Gasturbine V94 Zehn Jahre im Einsatz“,
VGB Kraftwerkstechnik 1986, vol. 8, pp 722 - 728

[6.] **Grünewald, G.** “Selective Physical Absorption using the Purisol Process as an Example”, 6th Continental Meeting of the GPA, Bremen 1989, GPA

[7.] **Tummers, J. F., et al** “Clean Energy Production from Heavy Residual Oil Gasification-based Combined-cycle Power Stations”. Second Seminar on Desulphurization of Fuels and Combustion Gases, Washington 1975. Economic Commission for Europe

[8.] **Butzert, H. E.**, “Newly Developed Features in VEBA Ammonia Plant”. AIChE Symposium on Safety in Ammonia Plant and Related Facilities. Boston 1975

[9.] **Henneforth, J. C.**, “Watson Cogeneration Project - A Case History”. Power-Gen '89, New Orleans, Dec. 1989